Searches for Long-Lived Particles at the LHC

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Charged Long-Lived Particles Signatures

- Heavy charged particle, stable from the point of view of the detector, detectable as high momentum tracks with an anomalously large rate of energy loss through ionization and an anomalously long time-of-flight

CMS: Slow Heavy Stable Charged Particles (arXiv:1205.0272)

ATLAS: Charged Long-Lived Particle (Pixel-like) (ATLAS-CONF-2012-022)

- Very slow charged particles that are stopped in the detector volume and decay later giving signal in calorimeter

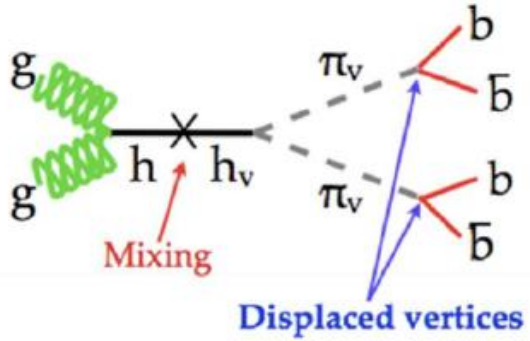
CMS: Stopped Heavy Stable Charged Particles (PAS EXO-11-020)

- Heavy charged particles that decay to neutral and very soft particles, that are not reconstructed

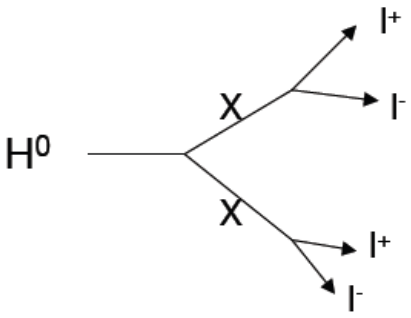
ATLAS: Disappearing tracks (ATLAS-CONF-2012-034)

Neutral Long-Lived Particles Signatures

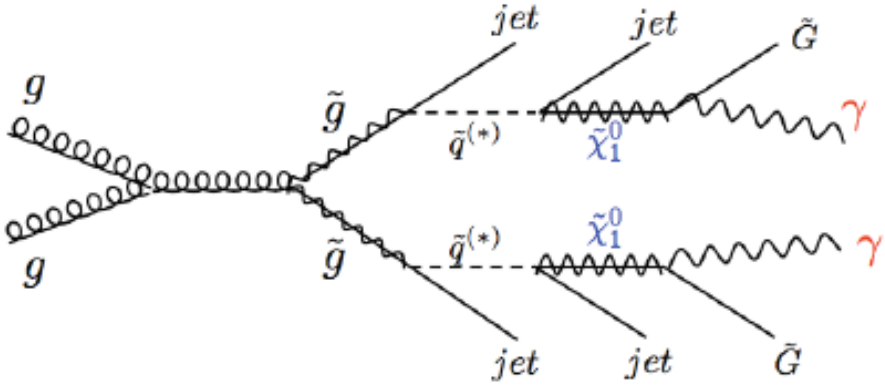
ATLAS:
Displaced jet vertices in the Muon Spectrometer
(arXiv:1203.1303)

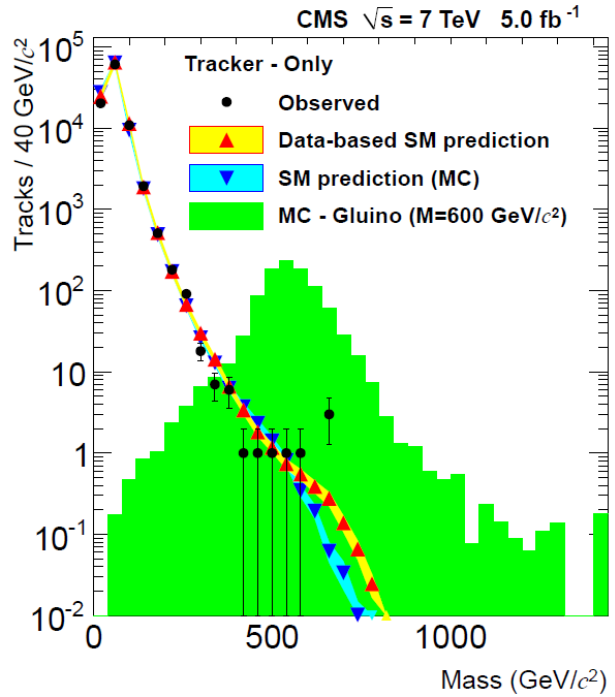


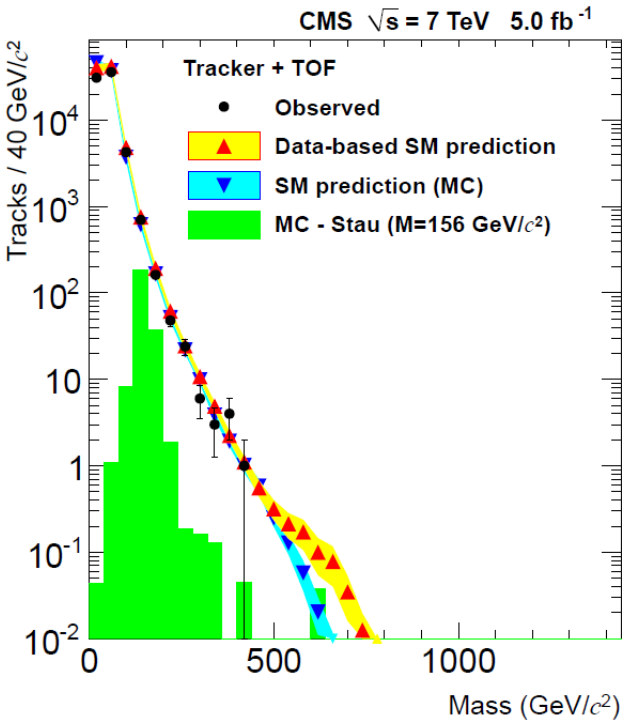
CMS:
Pair of leptons originating from common vertex displaced from LHC beam spot
(PAS EXO-11-004)



CMS:
Two isolated photons displaced from LHC beam spot converting to e^+e^- pairs
(PAS EXO-11-067)



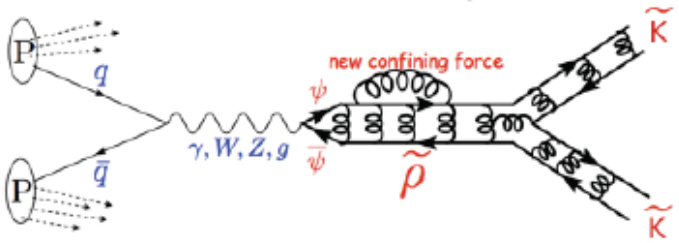


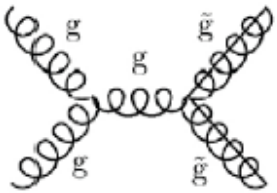


Slow HSCP

Models: arXiv:1205.0272

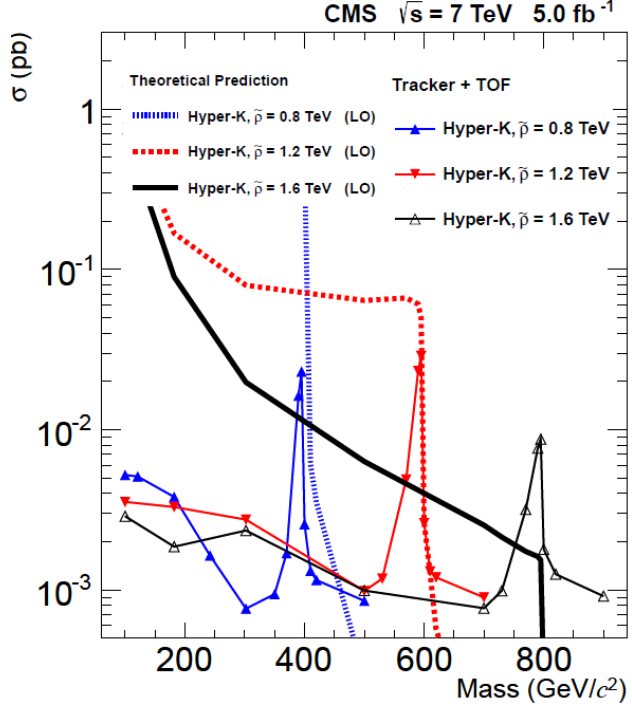
- R-hadrons: gluino, stop
  - Two interaction models: cloud and conservative charge suppresion
  - R-gluonball fractions: 0.1, 0.5
- Lepton-like:
  - Stau (direct pair production, GMSB)
  - Pair produced Hyper-kaon (through DY + hyper-ρ resonance)

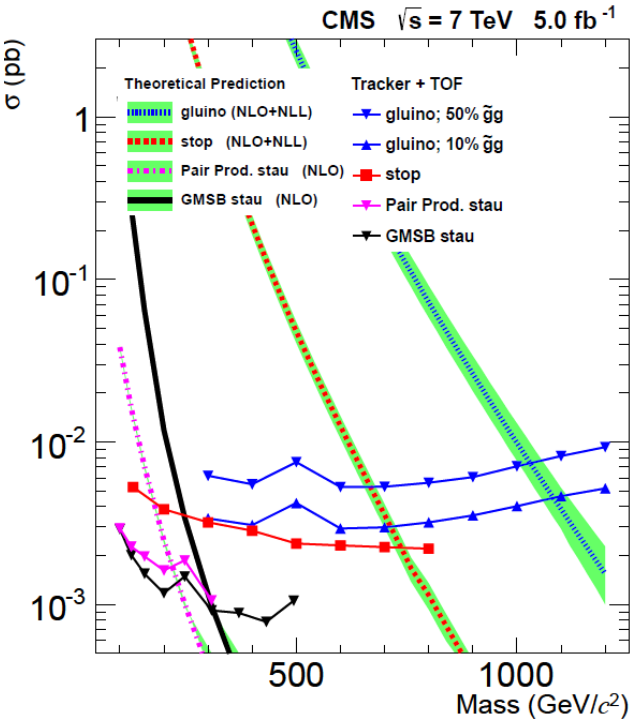




Two selection strategies:

- Tracker-only: large dE/dx + large p_T
- Tracker+TOF: Tracker-only + μ-like + long time-of-flight (β^{-1} from μ system)





Slow HSCP

arXiv:1205.0272

Triggers:

- Single μ, MET (for charge suppression models), HSCP dedicated RPC trigger. 75% (10%) efficiency for staus with β = 0.6 (0.45)

Data-driven background estimation:

- Utilizing the non-correlation between β^{-1}, dE/dx MIP-compatibility (I_{as}) and p_T. Mass prediction using p, I_h and β^{-1} PDF from non-signal region

Limits:

Cloud model interaction scenario

Gluino (10% gg): 1098 GeV, Stop: 737 GeV

Charge suppression interaction scenario

Gluino(10% gg): 928 GeV, Stop: 626 GeV

Direct pair produced stau:

223 GeV

Hyper-kaon:

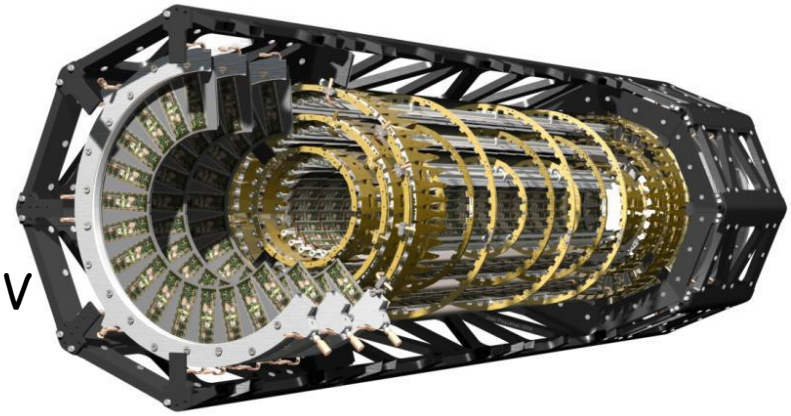
484, 602 and 747 GeV for hyper-ρ masses of: 800, 1200 and 1600 GeV

Charged Long-Lived (pixel)

ATLAS EXPERIMENT

Trigger: ATLAS-CONF-2012-022

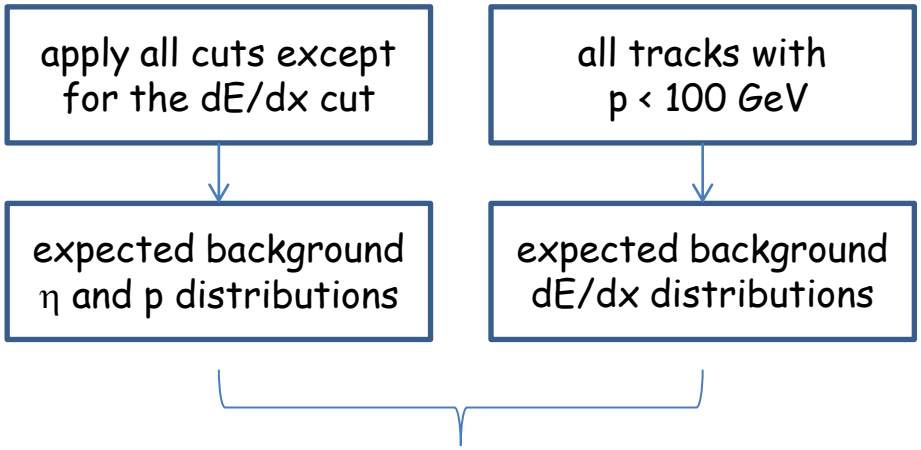
- MET > 70 GeV (~20% acceptance)



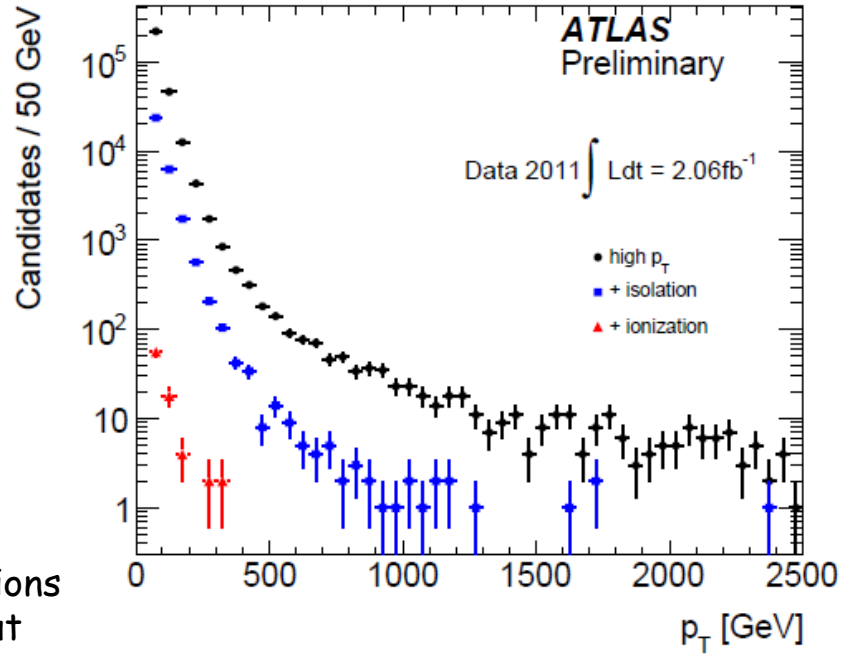
Offline selection:

- MET > 85 GeV
- Good isolated track p_T > 50 GeV, p > 100 GeV
- dE/dx cut η dependent

Data Driven Background:



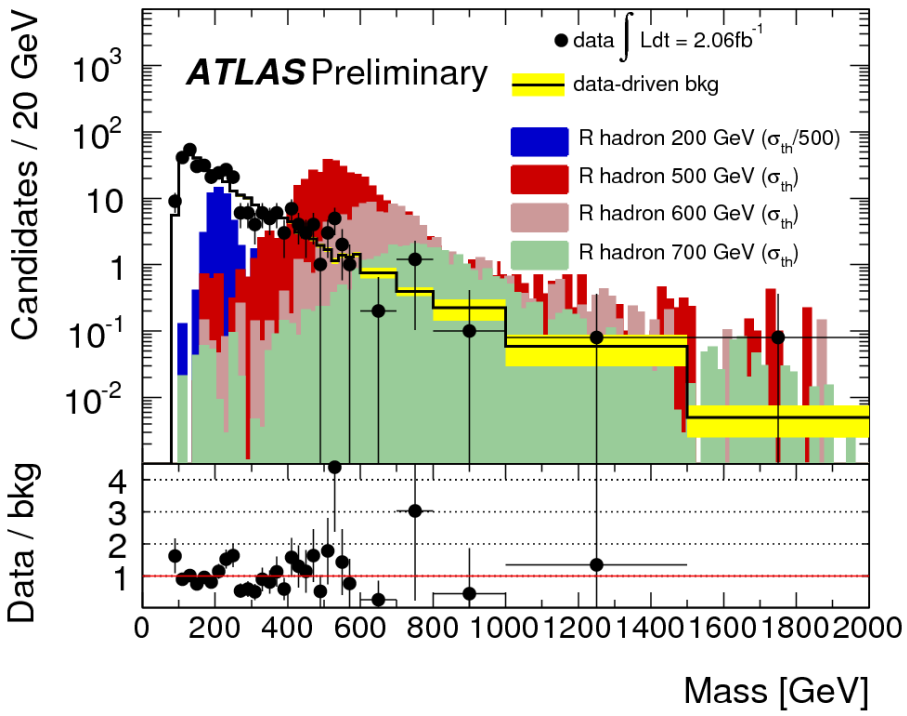
- randomly sample p,η and dE/dx from these distributions
- normalize to data in low mass region before dE/dx cut

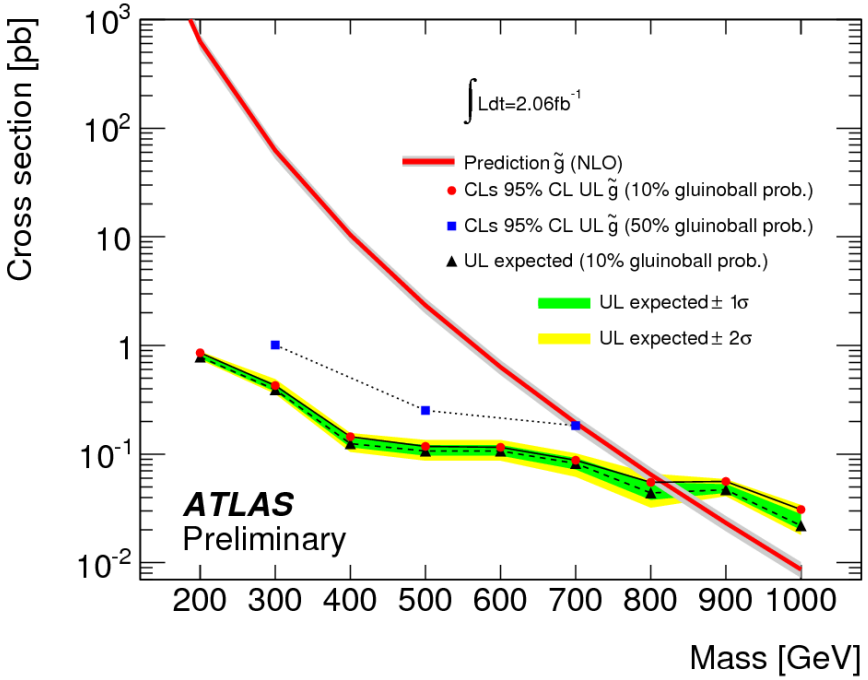


Charged Long-Lived (pixel)

ATLAS EXPERIMENT

ATLAS-CONF-2012-022





333 events are observed in data as is consistent with background estimation.

With some model dependent assumptions, this can be interpreted as excluding gluino R-hadrons with masses smaller than 810 GeV.

Stopped HSCP

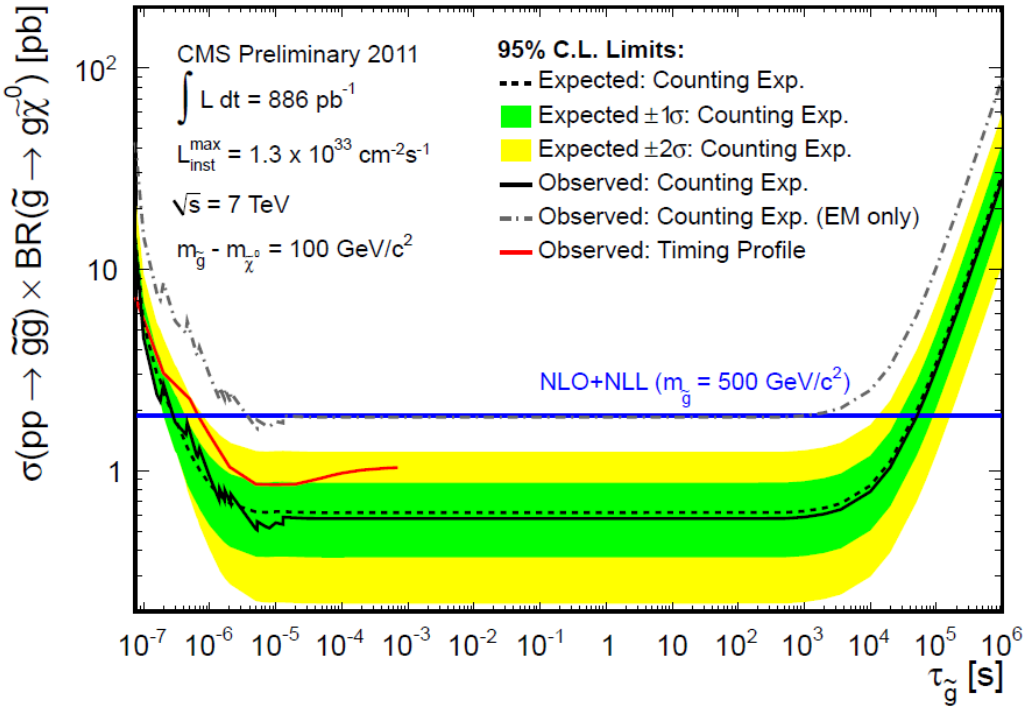
PAS EXO-11-020

Trigger: Dedicated 50 GeV Single Jet trigger with no signals from beam position and timing (BPTX) monitors in a window of ±1 Bunch Crossing (BX)

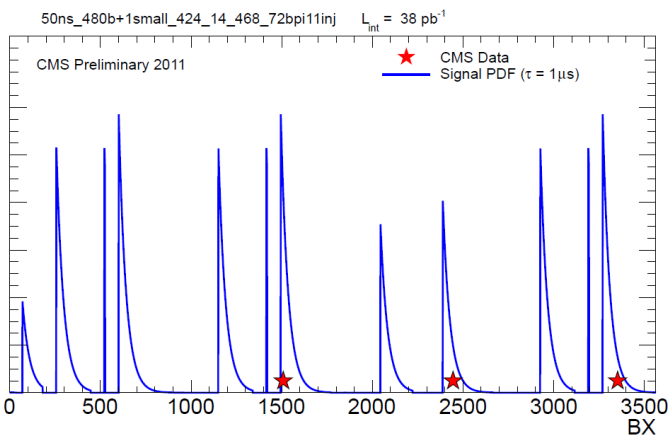
Background rate:

- $1.7 \pm 0.7 \times 10^{-5}$ Hz from beam-related, cosmic rays, and detector noise
- Signal efficiency ~13%
- Noise and cosmic rates from 2010 data (36 pb^{-1})

Methods: Counting experiment and timing profile analysis



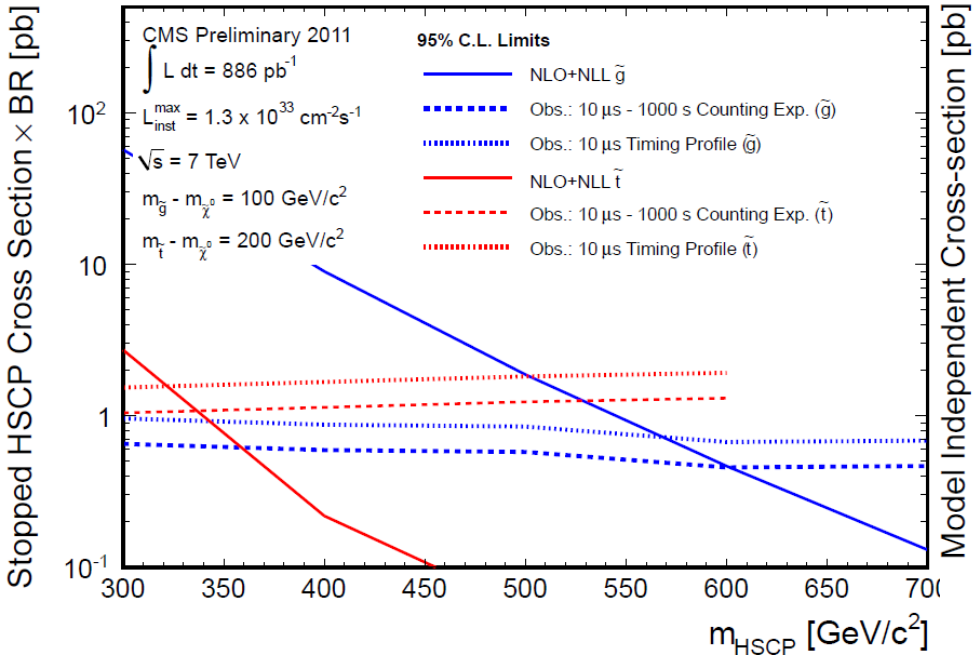
Lifetime	$L_{eff}(pb^{-1})$	Expected Bg	Observed
75 ns	4.3	0.11 ± 0.05	0
100 ns	12.5	0.35 ± 0.14	0
1 μs	139	3.3 ± 1.3	4
10 μs	352	10.1 ± 4.1	9
30 μs - 10^3 s	360	10.4 ± 4.2	10
10^4 s	268	10.4 ± 4.2	10
10^5 s	65	10.4 ± 4.2	10
10^6 s	7.5	10.4 ± 4.2	10

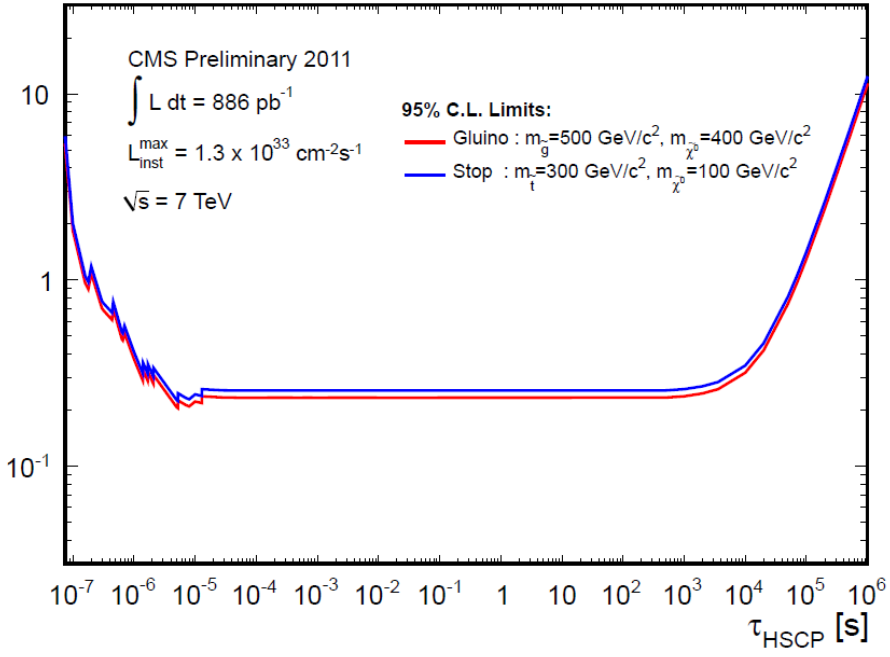


Stopped HSCP

PAS EXO-11-020

- 95% CL mass exclusion limits assuming $10^{-6}<\tau<10^{3}$ s:
  - m_{gluino} < 601 GeV
  - m_{stop} <337 GeV
- 95% CL limits on cross section x BR x stopping efficiency are independent of interaction model



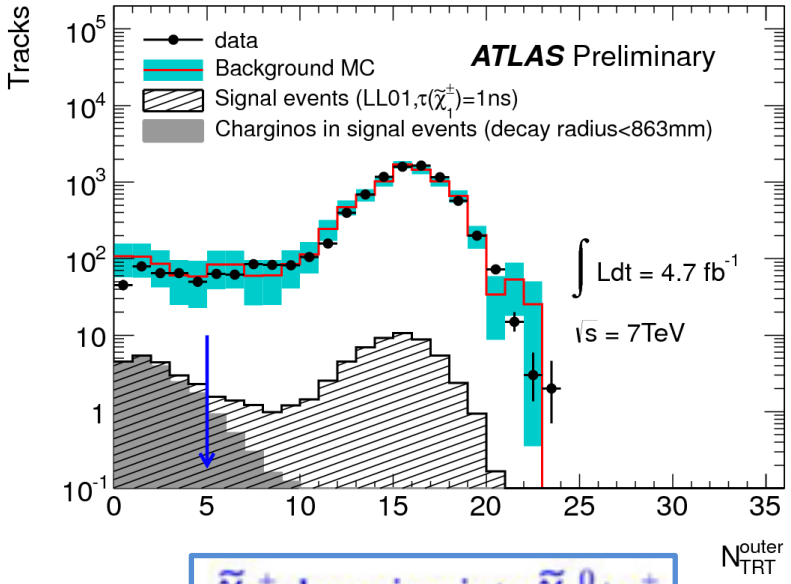


Disappearing tracks

ATLAS-CONF-2012-034

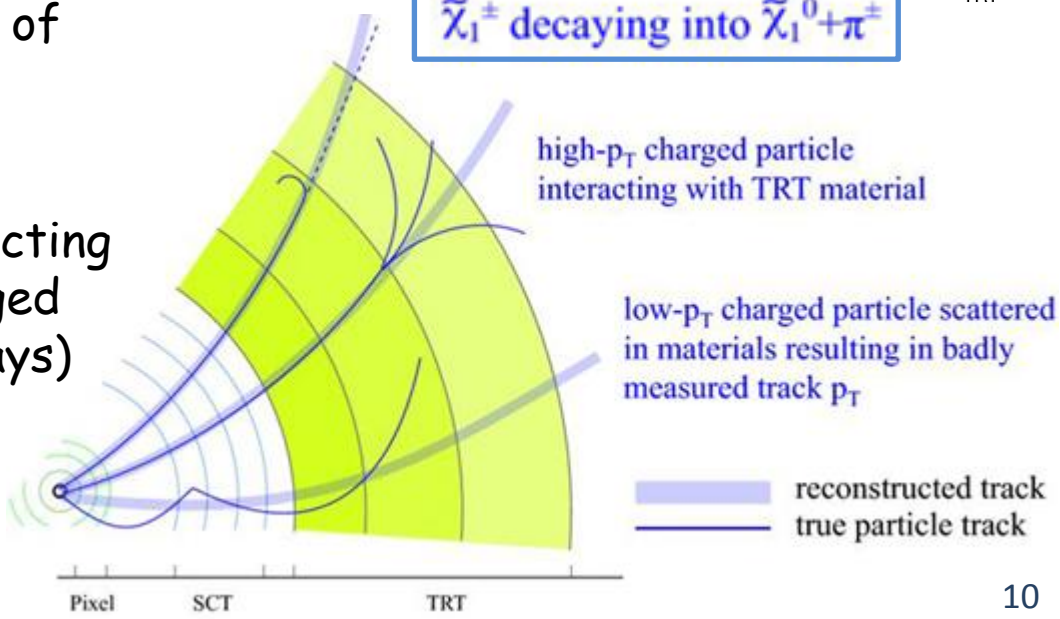
AMSB: $\tilde{\chi}_1^{\pm} \rightarrow \tilde{\chi}_1^0 + \pi^{\pm}$

- Trigger: MET > 55 GeV, 1 jet p_T > 75 GeV
- Selection: MET >130 GeV,
  3 jets with pT > 160, 60, 60 GeV
- Isolated high quality tracks, p_T > 10 GeV
- Reconstructed primary vertex, lepton veto
- Signal efficiency ~7%, signal purity ~94%
- Disappearing tracks are identified by less then 5 hits in the outer layer of the Transition Radiation Tracker



Background:

- Dominant: Charged particle interacting with tracker material (from charged hadrons, jets, and hadronic τ decays)
- Tracks with badly measured p_T
  - Background estimated with data driven method



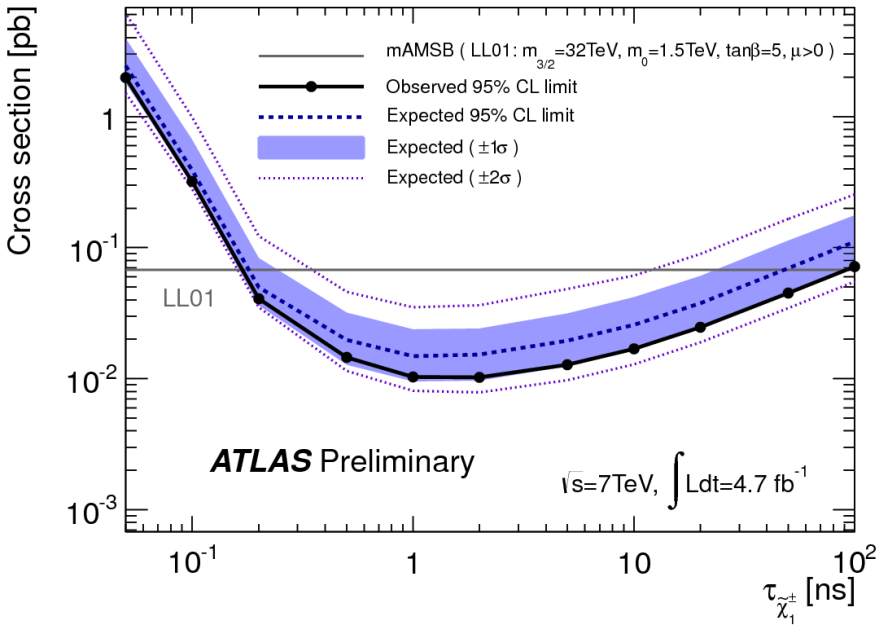
Disappearing tracks

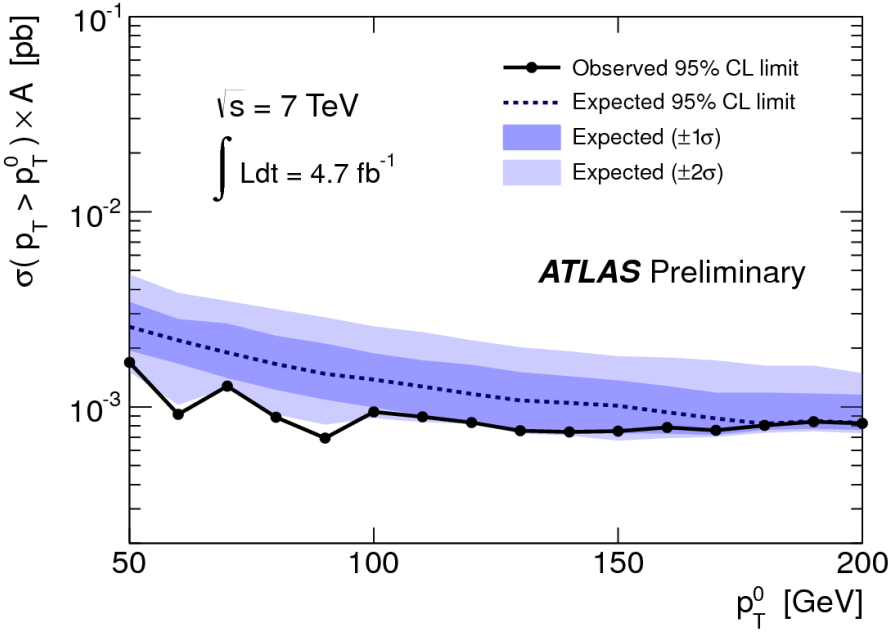
ATLAS EXPERIMENT

[ATLAS-CONF-2012-034]

Sample	m_0[TeV]	$m_{3/2}$[TeV]	$m_{\tilde{\chi}_1^\pm}$[GeV]	Cross section[pb]
LL01	1.5	32	90.2	6.79×10^{-2}
LL02	1.8	41	117.8	8.66×10^{-3}
LL03	2.0	51	147.7	1.16×10^{-3}

Excluded lifetimes:
- LL01 → 0.2 – 90 ns
- LL02 → 1-2 ns





The observed and expected 95% CL upper limits on the signal cross section as a function of the chargino lifetime for m(chargino) = 90.2 GeV.

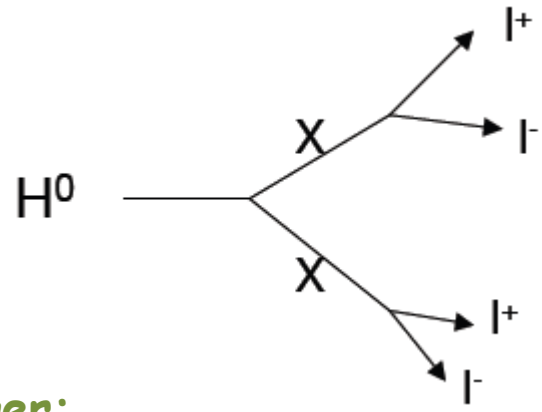
Model-independent limit for new physics process with an isolated, disappearing track

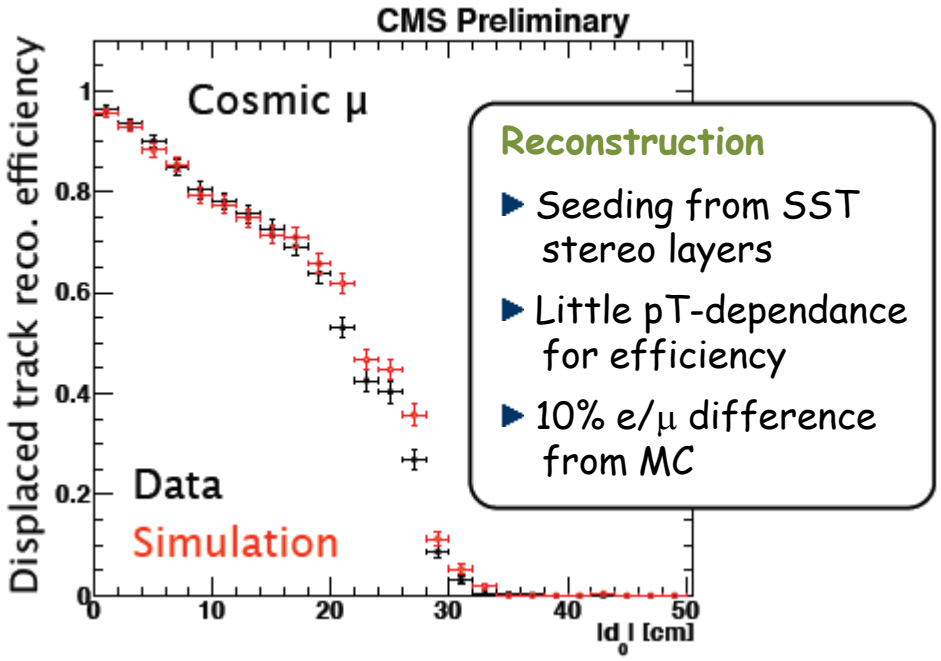
Displaced Leptons

PAS EXO-11-004

Model: Split SUSY

- $gg \rightarrow H^0 \rightarrow 2X$, $X \rightarrow l^+l^-$
- X is long-lived, spin 0
- Consider $200 < M_H < 1000$ GeV and $20 < m_X < 500$ GeV
- Assume ee/μμ are each 50% of l^+l^-





Trigger:

- di-μ(γ) each with pT>33(23) GeV

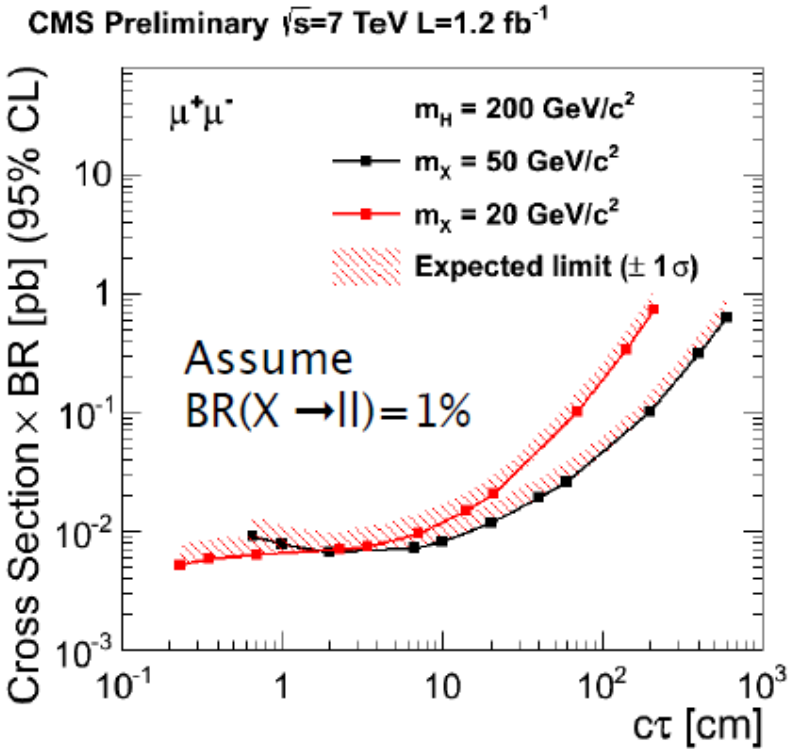
Selection:

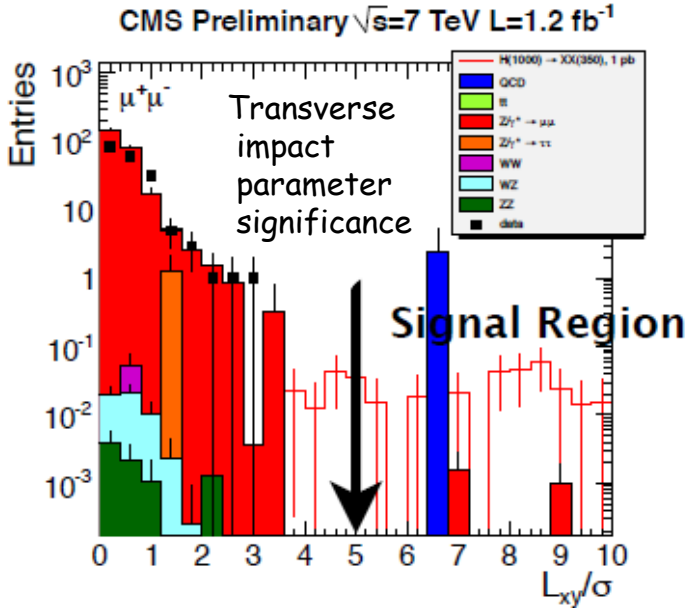
- primary vertex; isolated, high purity track
- opposite charged pair with well fitted common secondary vertex
- collinearity angle< 0.2(0.8) between dilepton
- total momentum and vector from primary to secondary vertex
- lepton-ID: only trigger matching required

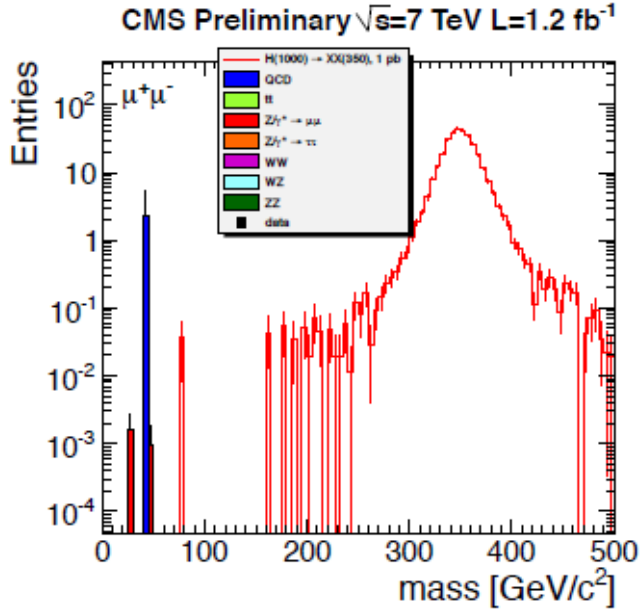
Displaced Leptons

PAS EXO-11-004

- Background estimate from fit to MC in control region, extrapolated to signal region
- $L_{XY} \approx 4$cm for backgrounds
- 95% CL_S cross section limits vs. $c\tau$
  - Typically 3-30 fb for $c\tau \approx 1$m



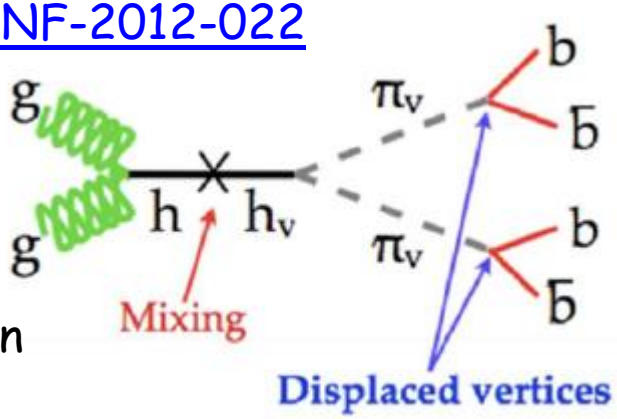


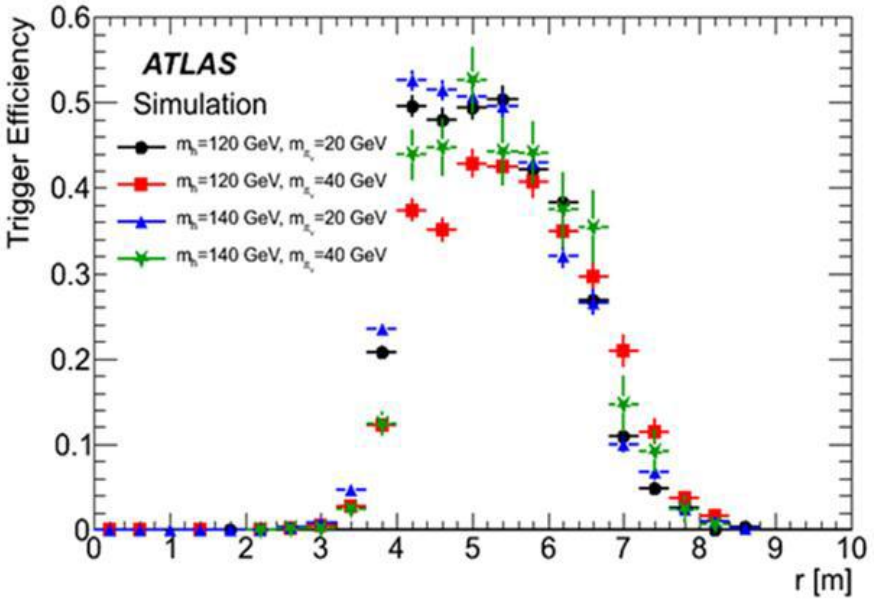


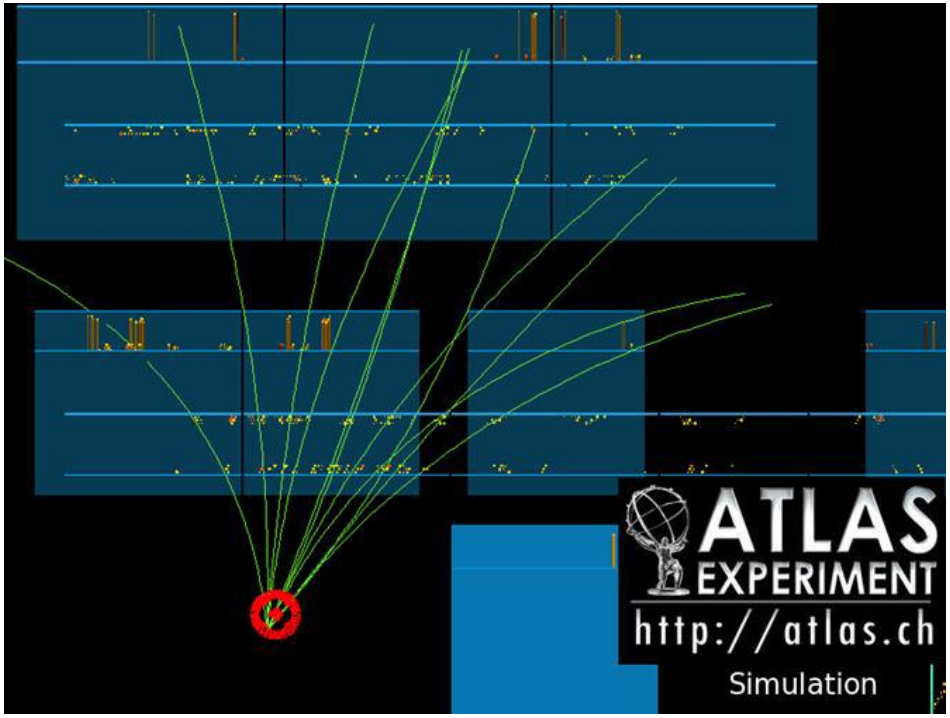
Higgs -> Long-Lived (Hidden Valley)

- Signal: Displaced Vertices near or in the Muon Spectrometer
- A special signature driven trigger - improvement of efficiency by an order of magnitude at high radius: it selects a cluster of 3 or more ROIs in $\Delta R=0.4$ cone
- Background rejection: calorimeter and tracker isolation
- Control sample: punch-through jets
- Final selection: 2 good MS vertices separated by $\Delta R > 2$

ATLAS-CONF-2012-022





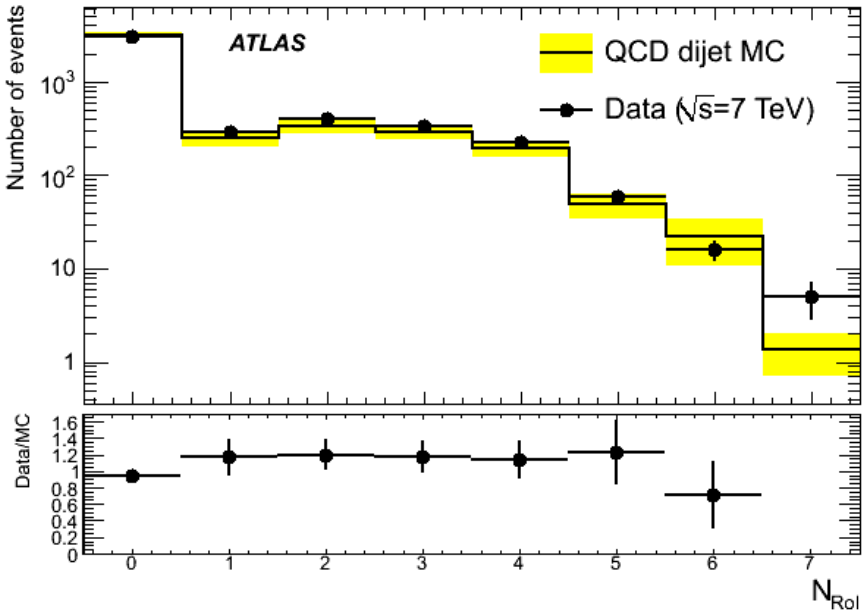


Higgs -> Long-Lived (Hidden Valley)

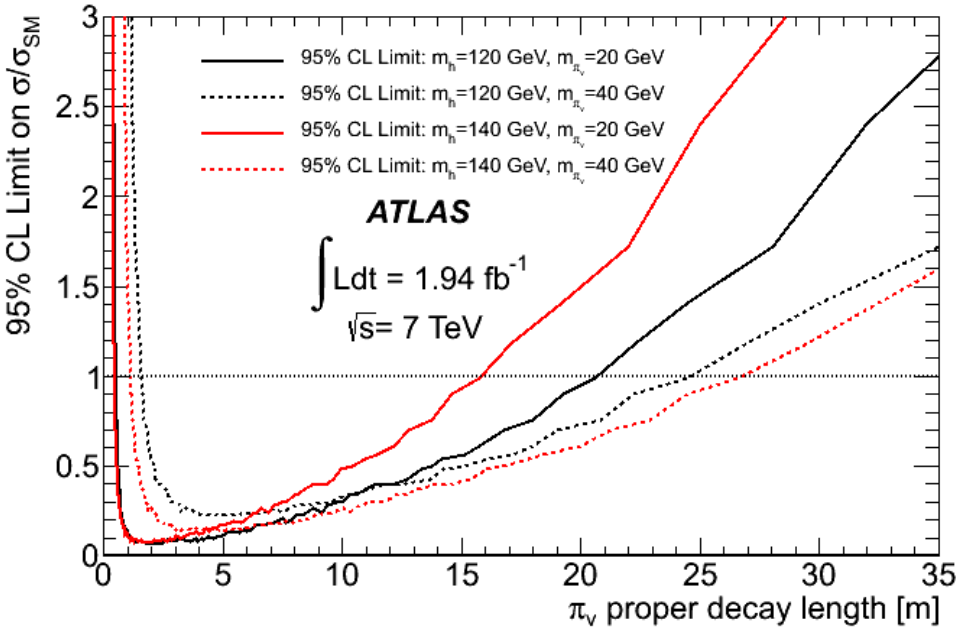
- Zero events observed meeting the analysis selection in 1.94 fb^{-1}
- Exclusion limits assume 100% branching ratio for low-mass Higgs to v-pions

ATLAS-CONF-2012-022

m_{h^0} (GeV)	m_{π_v} (GeV)	Excluded Region
120	20	$0.50 < c\tau < 20.65$ m
120	40	$1.60 < c\tau < 24.65$ m
140	20	$0.45 < c\tau < 15.8$ m
140	40	$1.10 < c\tau < 26.75$ m



Distribution of number of events vs. number of muon RoIs from punch-through jets contained in the muon RoI cluster for both data and MC events.

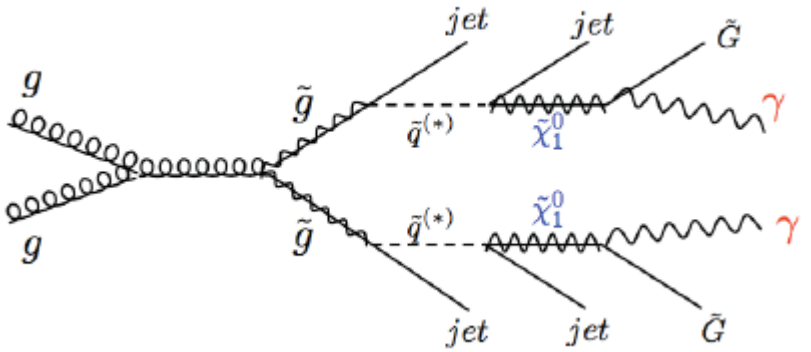


Displaced Photons

PAS EXO-11-067

Model:

- GMSB SPS8: $\tilde{\chi}_1^0 \to \gamma\tilde{G}$
- 140 GeV neutralino, 2 < cτ < 25 cm
- high p_T jets, MET, 2 displaced photons



Trigger:

- Diphoton 32(22) < E_T < 40(28) GeV for leading (sub-leading) photon

$$d_{XY} = -L_X \cdot \sin\phi + L_Y \cdot \cos\phi$$

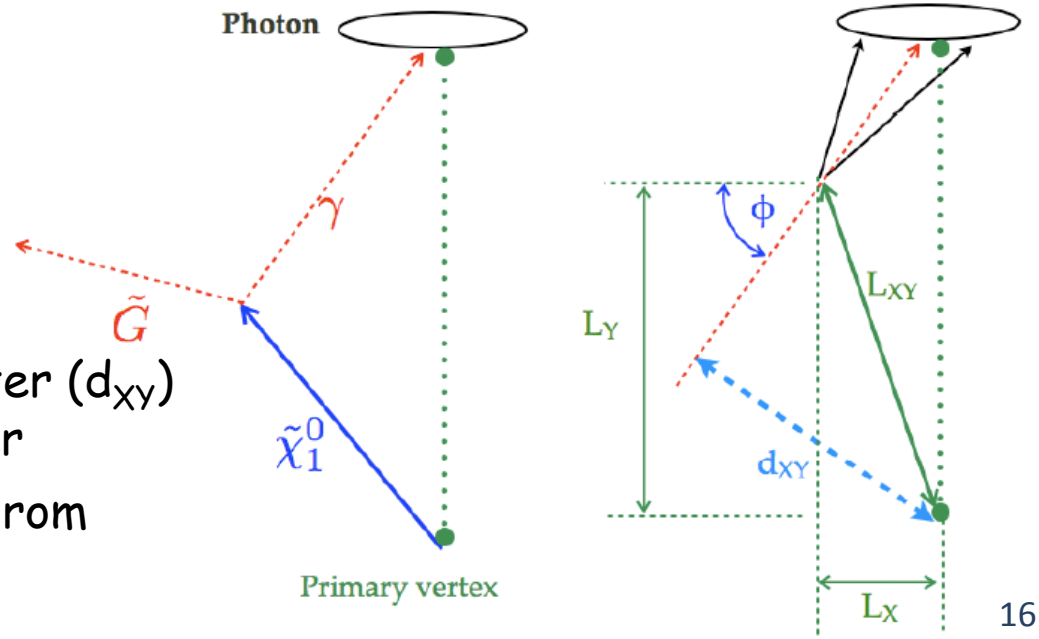
$$d_Z = L_Z - \frac{L_X \cdot p_X + L_Y \cdot p_Y}{p_T} \cdot \frac{p_Z}{p_T}$$

Offline Selection:

- isolated photon E_T>45 GeV,
- jets: p_{T1}>80, p_{T2}>50 GeV in |η|<2.6
- MET > 30 GeV

Conversion reconstruction:

- Determine photon impact parameter (d_{XY}) from $\gamma \to ee$ conversions in tracker
- Conversion reco systematic 20% from $Z \to \mu\mu\gamma$ data-MC comparison



Displaced Photons

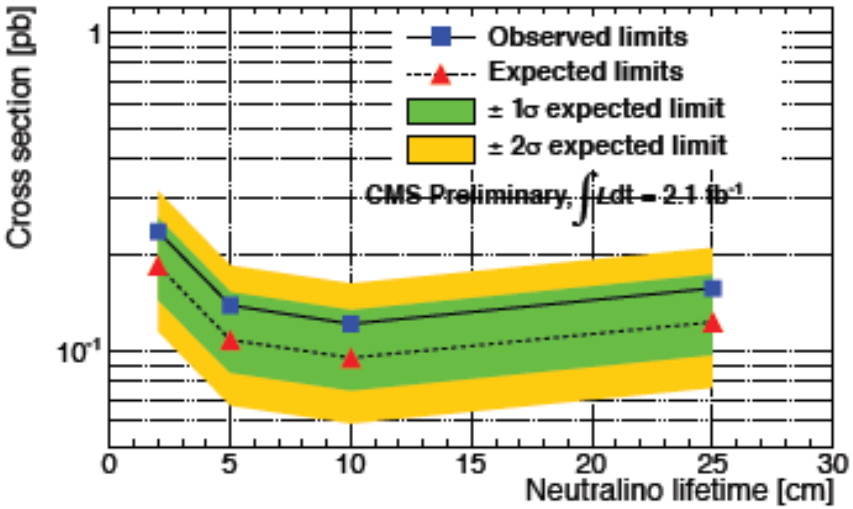
PAS EXO-11-067

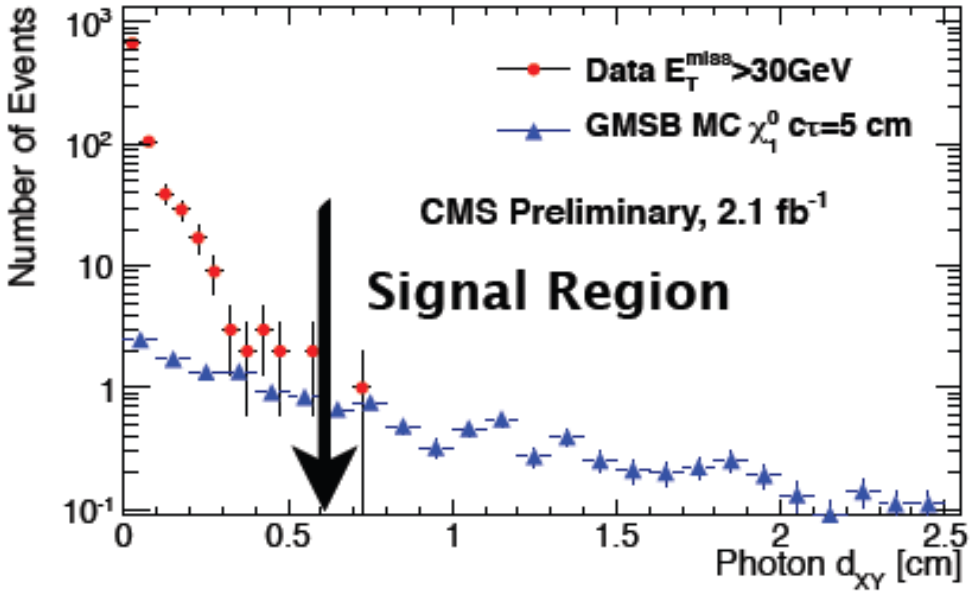
Data-Driven Background estimation:

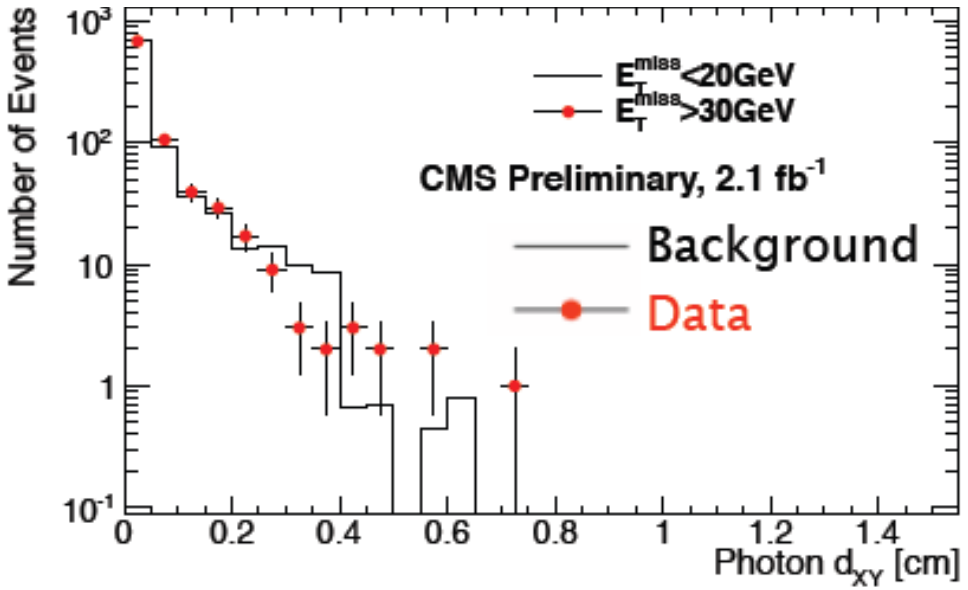
- compare d_{XY} in isolated/non-isolated and high-MET/low-MET regions
  - d_{XY} shape independent of MET and isolation.
- Use low-MET control sample for background shape

Cross section limits

- 95% CL_S 0.1-0.25 pb depending on $c\tau$







Summary

- Both CMS and ATLAS experiments have extensive programs to search for new long-lived particles
- Various long-lived particle signatures from a number of BSM models have been tested:
  - stopped and slow moving charged, heavy particles
  - disappearing tracks
  - displaced jet vertices
  - displaced dileptons
  - displaced photons

  No significant excess observed
- 95% C.L. cross section limits have been set

  Significant improvement over 2010 data limits
- Results shown are available:

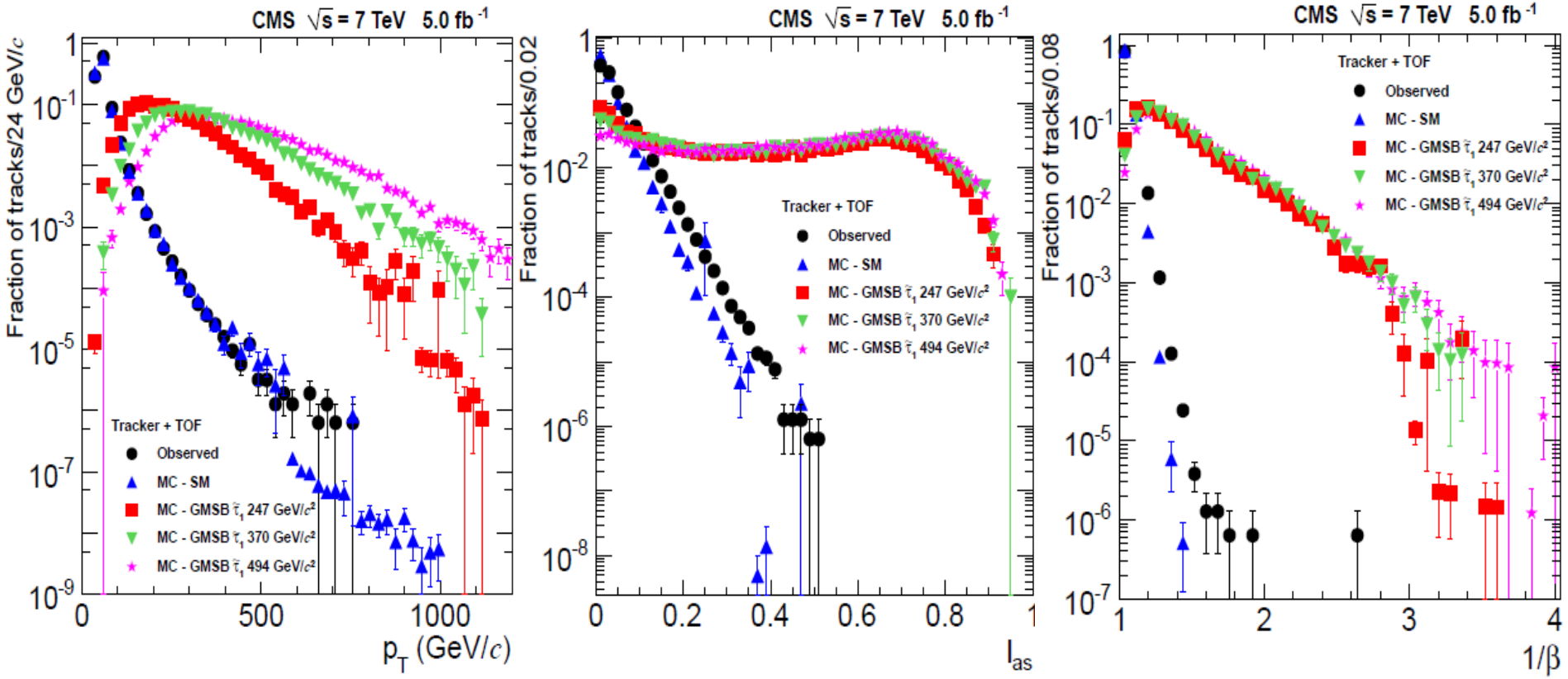
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ExoticsPublicResults
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults

BACKUP

Searches for Long-Lived Particles at the LHC with 2011 Data

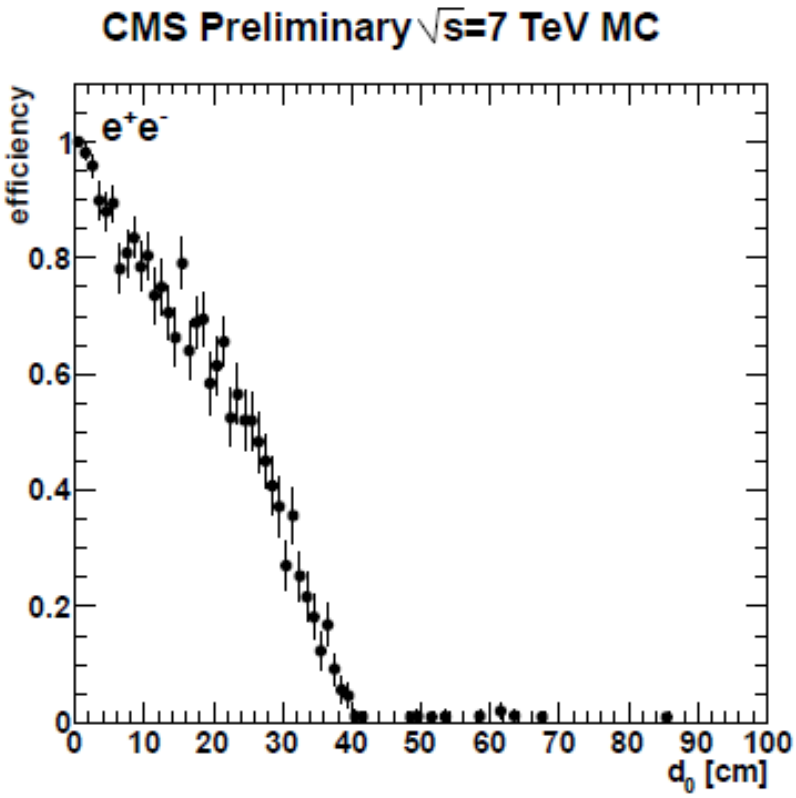
CMS	ATLAS
Slow Heavy Stable Charged Particles (5 fb^{-1}) arXiv:1205.0272	Charged Long-Lived Particle (Pixel-like) (2.0 fb^{-1}) ATLAS-CONF-2012-022
Stopped Heavy Stable Charged Particles (0.9 fb^{-1}) PAS EXO-11-020	Disappearing tracks (4.7 fb^{-1}) ATLAS-CONF-2012-034
Displaced leptons (1.2 fb^{-1}) PAS EXO-11-004	Higgs boson decaying to Long-Lived particles (1.94 fb^{-1}) arXiv:1203.1303
Displaced photons (2.1 fb^{-1}) PAS EXO-11-067	

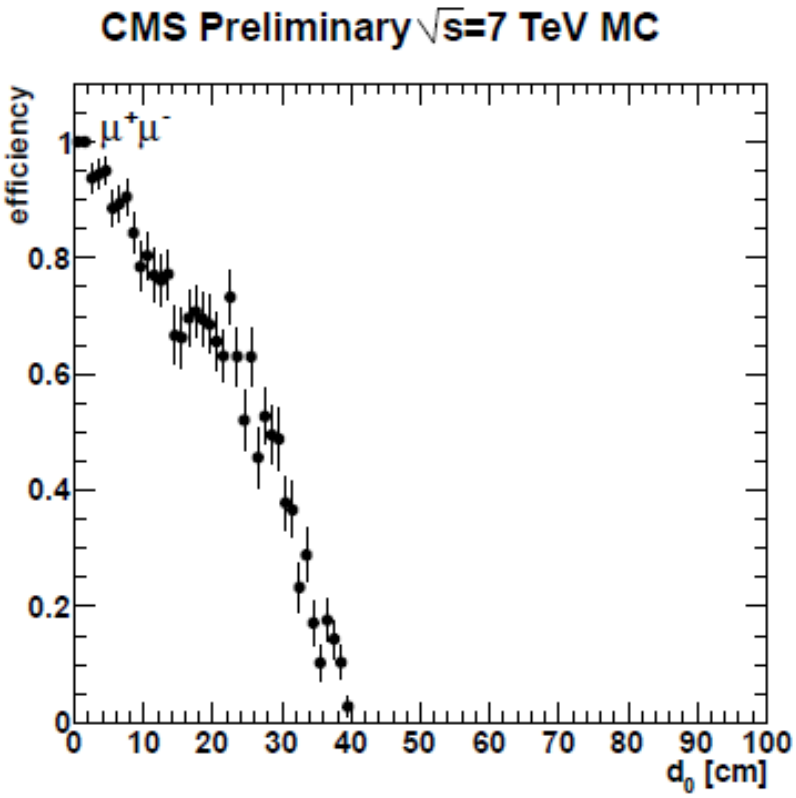
Slow HSCP



Normalized distributions of p_T, I_{as}, and β^{-1} in data, simulated SM processes and some of the simulated signal samples for the tracker+TOF selection

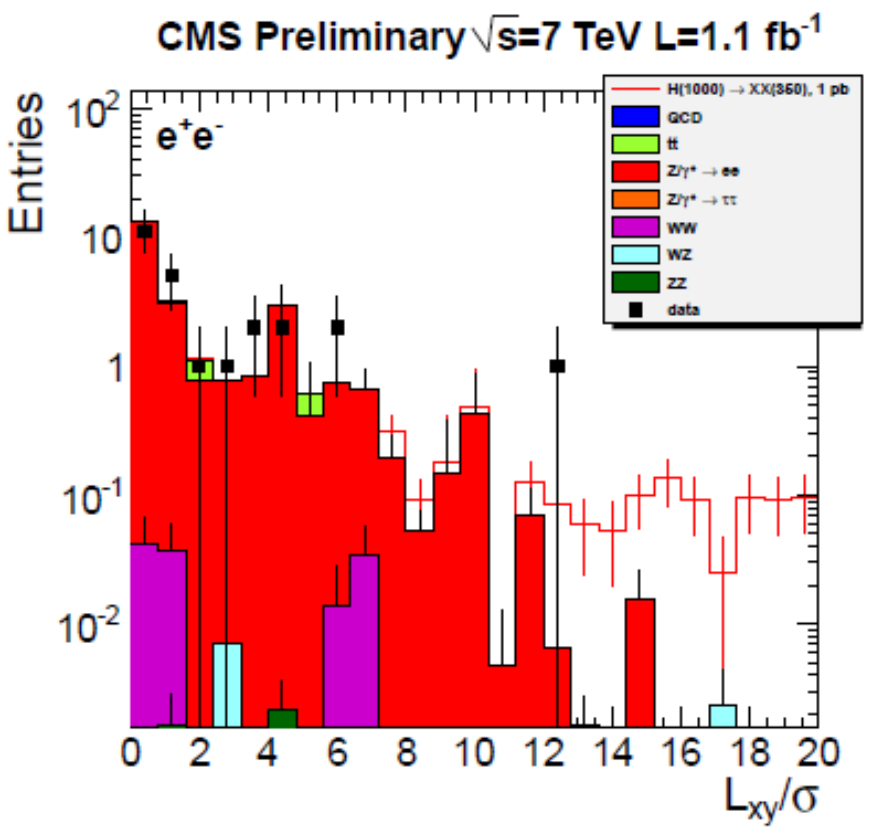
Displaced Leptons



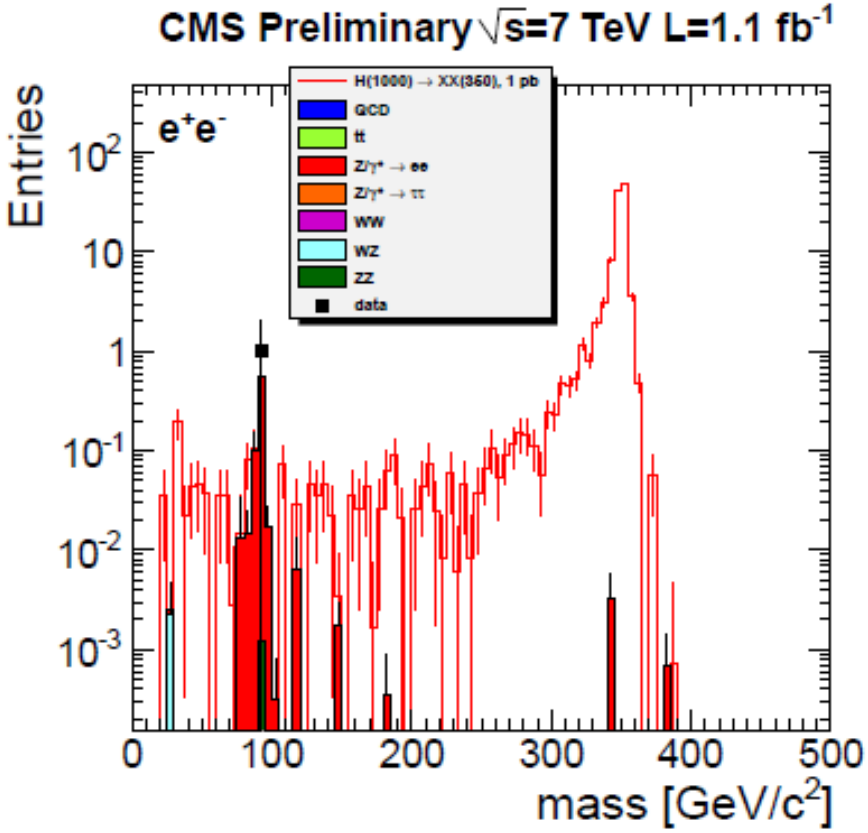


Track reconstruction efficiency for single, isolated electrons (left) and muons (right) of p_T = 50 GeV as a function of the transverse impact parameter. The efficiency has little dependence on p_T

Displaced Leptons

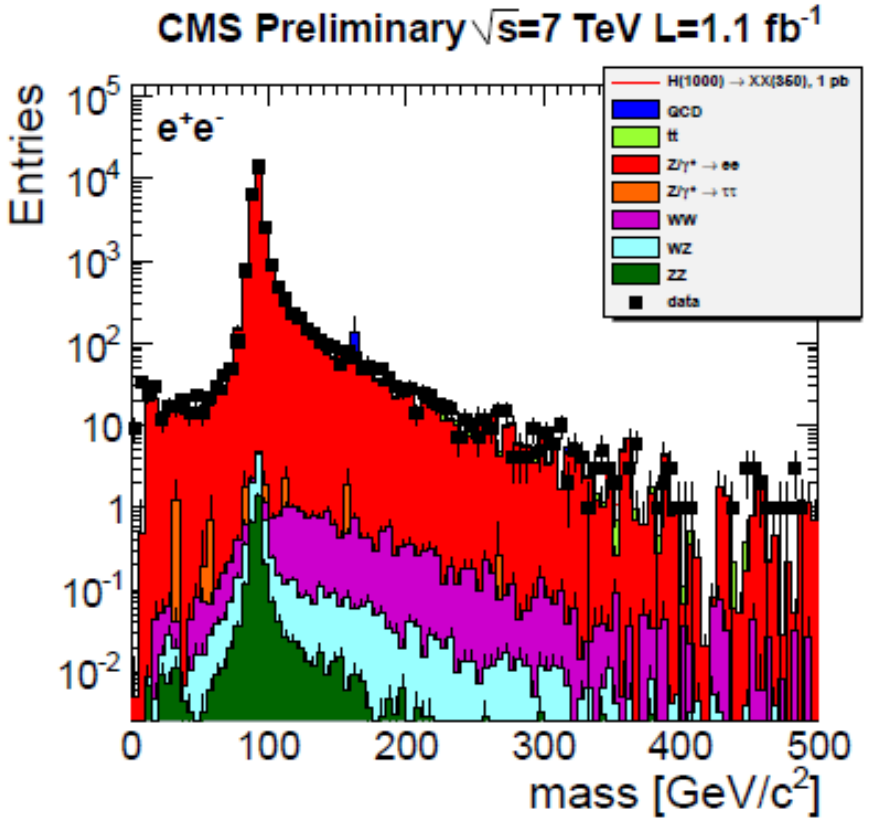


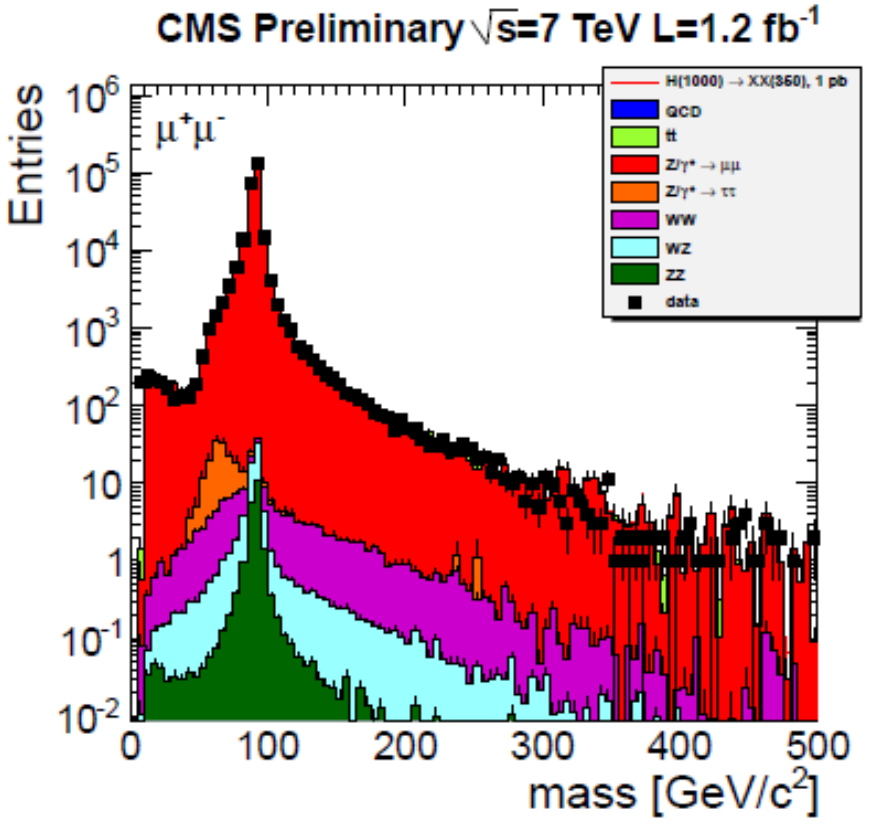
The transverse decay length significance of the candidates for the dielectron channel. It is required to be more than 8.



The reconstructed dielectron mass after all selection cuts have been applied. The dielectron channel shows residual Z background in the selection.

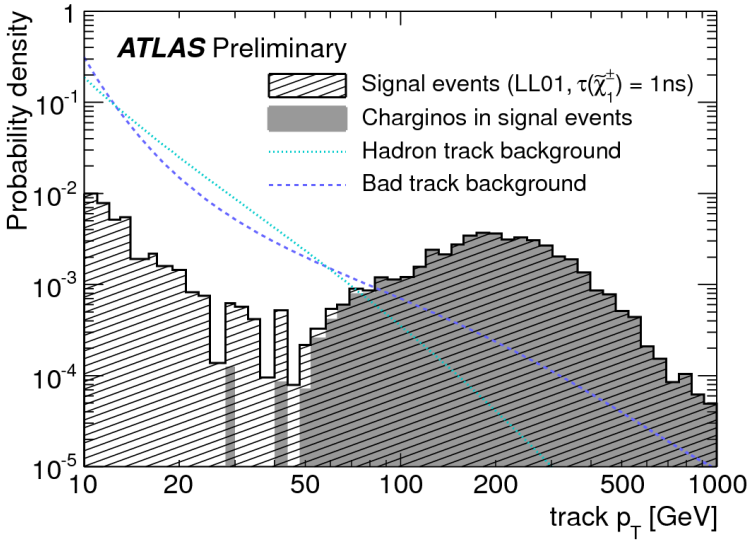
Displaced Leptons



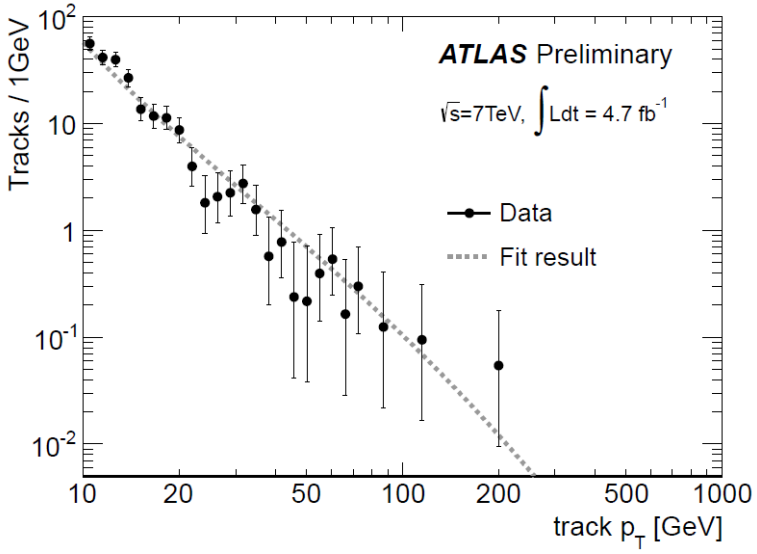


The invariant mass distribution of dielectron (left) and dimuon (right) candidates after applying all selection cuts except the ones on transverse impact parameter and on vertex flight direction, and with the decay length significance cut inverted. This predominantly selects prompt background such as Z bosons

Disappearing Tracks



Probability densities for the signal and background components, shown as a function of track p_T

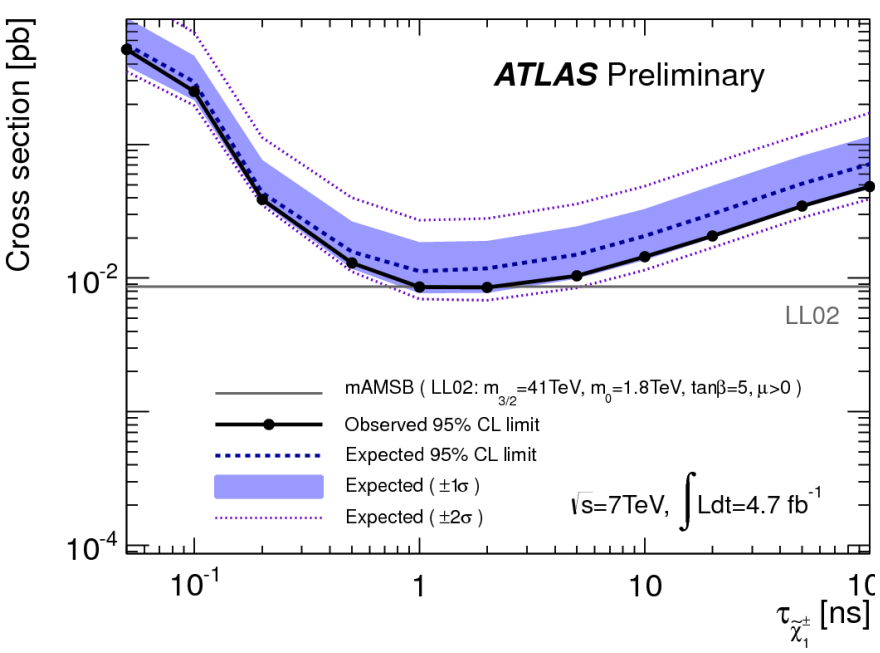


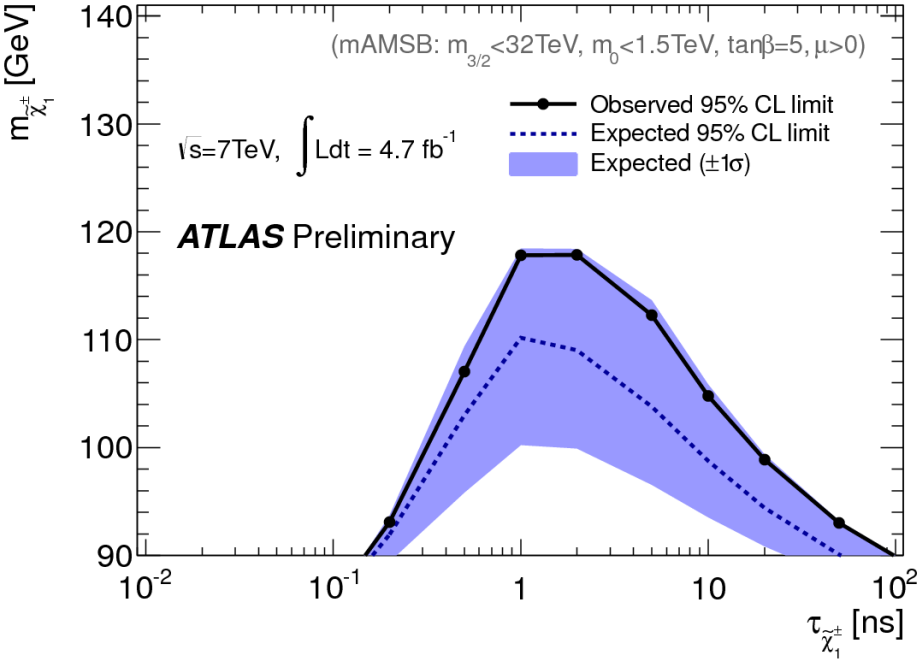
Candidate tracks (signal + background model)

Requirement	Observed events	Signal efficiency (purity) [%]		
		LL01	LL02	LL03
Trigger selection and non-collision rejection	7141026	87.3	89.1	90.1
Lepton veto	6644394	72.8	72.5	72.6
$E_T^{miss} > 130$ GeV	321412	66.5	68.2	69.6
Jet requirements	73433	64.9	67.4	69.0
High-p_T isolated track selection	8458	24.8 (67.6)	26.2 (66.8)	27.2 (66.7)
Disappearing track selection	304	6.1 (94.6)	6.6 (94.5)	7.3 (94.7)

Summary of selection cuts

Disappearing Tracks

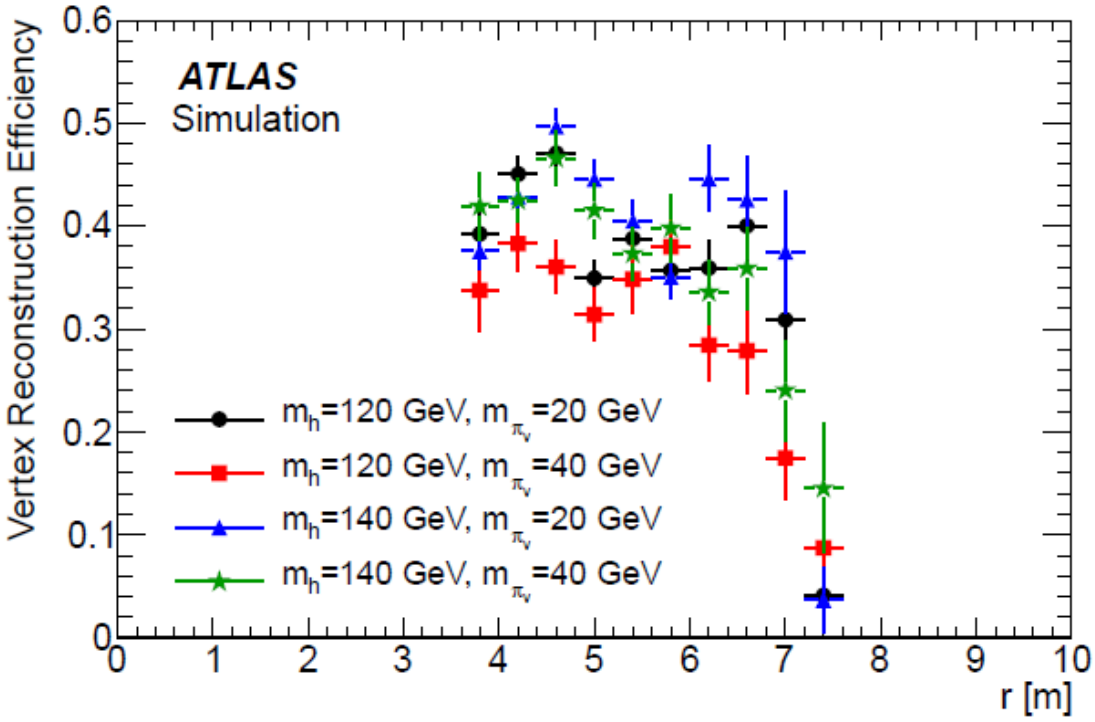




The observed and expected upper limits on the cross section as a function of the chargino lifetime at 95% CL for chargino mass = 117.8GeV

The constraint on chargino mass and chargino lifetime at 95% CL

Higgs -> Long-Lived (Hidden Valley)



The vertex reconstruction efficiency for π_v decays in the barrel for events that pass the muon RoI cluster trigger as a function of the radial decay distance.